PHYTOPLANKTON AS INDEX OF WATER QUALITY WITH REFERENCE TO POLLUTION OF THE GANGA RIVER FROM MUNGER TO MANIHARI, BIHAR (INDIA)

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Abstract:** In the present study, an attempt was made to study water quality and the phytoplankton diversity index at eight sampling station of the River Ganga in 180km stretch from Munger to Manihari, Bihar in pre and post-monsoon. Various water quality parameters including ambient temperature, water temperature, total dissolved solid, conductivity, turbidity, pH, dissolved oxygen, free carbon dioxide, bicarbonate, total hardness, chloride, phosphate-phosphorus, nitrate- nitrogen, COD and BOD were analyzed. Turbidity, total hardness, COD and BOD were above the permissible limit. Water quality parameters varies with Ambient Temperature 23.5-33°C and 13.4-29.5°C, Water Temperature 24.1-25°C and 17-24.3°C, Turbidity 5.6-17.7NTU and 12.4-29.9NTU, Conductivity 271-395µs and 222-383µs, TDS 139-201mg/l and 113-195mg/l , pH 7.5- 8.2 and 6.4-8.8, DO 6-9.6mg/l and 4.5-9.6mg/l, FCO_2 6-70mg/l and 24-80mg/l, HCO_3^- 32-44mg/l and 26-40mg/l, TH 126-160mg/l and 120-170mg/l, Cl^- 15.98-27.99mg/l and 9.99-19.99mg/l, PO_4-p 0.054-0.084mg/l and 0.05-0.086mg/l , NO_3-N 0.041-0.047mg/l and 0.040-0.046mg/l, COD 38.9-69.6mg/l and 12.31-44.8mg/l, and BOD 0.8-2.8mg/l and 0.4-7.4mg/l in pre and post-monsoon respectively. A total of 57 genera and158 species of phytoplankton have been identified in pre and post-monsoon at all eight sampling station. According to pollution index of algal genera (Palmer, 1969), the index value was 32 indicating of organic pollution. Nygaard (1949) indices showed the values of chlorophycean and cyanophycean were eutrophic nature of water body while the euglenophycean and diatoms showed oligotrophic nature of water body. Shannon-Weaver diversity index (Sampling station first- 1.577-5.15, Sampling station second-1.022-1.0675, sampling station third- 1.293-1.675, sampling station fourth- 4.013-5.678, sampling station fifth-7.902-8.631, sampling station sixth- 1.111-1.675, sampling station seventh- 1.022-1.201and sampling station eighth 0.117-0.195) was applied to surface phytoplankton to study the water quality status of the River Ganga from Munger to Manihari receiving industrial effluents, fertilizers from agricultural lands, domestic sewage of municipal area and other sources.

***Key words:** Ganga River, Palmer indices, Nygaard indices, Shannon-Weaver index, Phytoplankton, water quality, pollution.*

INTRODUCTION

The Himalayas are the source of three major Indian rivers namely the Indus, the Ganga and the Brahmaputra. Ganga drains a basin of extraordinary variation in altitude, climate, land use, flora and fauna, social and cultural life. Ganga has been a cradle of human civilization since time immemorial. It is one of the most sacred rivers in the world and is deeply revered by the people of this country. Rapidly increasing population, rising standards of living and exponential growth of industrialization and urbanization have exposed the water resources, in general, and rivers, in particular, to various forms of degradation. River is a living eco-system and it is important in maintaining the balance of the ecosystem and it is also a main source of water for humans and animals that live in the surrounding area (Phillips, 1989). Rivers also play an important role in assimilating or carrying away industrial or municipal wastewater, run-off from agriculture area, sewage from urban areas, and any other anthropogenic factors. Thus, they are vulnerable to pollution (Farah Naemah, *et. al* 2000). Phytoplankton's are the main primary producer of an aquatic system and form an important component of food chain. The distribution of phytoplankton in time and space of environmental conditions are considered fundamental for any limnological study of natural waters. The quality and quantity of algal flora, its increase and decrease is governed by different abiotic and biotic factors as well as autotoxin. Various species diversity indices respond differently to different environmental and behavioral factors of biotic communities and therefore, recent investigations have been directed to species diversity indices. In water body usually occur seasonal qualitative fluctuations in plank tonic population in temperate and tropical climates (Jhingaran, 1980; Tiwari and Chauhan, 2006). The holy lower Ganga River from Munger to Manihari is the important for meanders, alluvial islands, and sandbars and also so many municipal waste water drains. The Knowledge of river phytoplankton of this stretch is fragmentary (Bilgrami and Datta Munshi, 1985, 1988; Choudhary, 1990.; Das and Maurya, 2015). In the present study, an attempt was made to study water quality and the phytoplankton diversity index in the Ganga River from Munger to Manihari.

MATERIALS AND METHODS

Collection of water and phytoplankton samples

Separates samples for river water and for phytoplankton collections were obtained from eight sampling stations during the pre monsoon and post monsoon of River Ganga in 2014. A total of 180km was surveyed from Munger (Kasthaharni Ghat) to Manihari (Singhal Tola Ghat) with a motor-powered country boat. The location of each sampling station was marked using a Garmin 12-channel GPS and the points were marked on the map (Fig. 1). Water samples for physico-chemical analysis were collected from various sampling stations in 1.5 liters polythene bottles. The parameters like temperature, pH, Dissolved oxygen, Free-carbon dioxide, Total dissolved solid, Conductivity was determined on the spot while the rest of the parameters were determined in the laboratory. The analysis was done as per standard methods of APHA (2005) and Trivedy and Goel (1986). Correlation coefficient was also computed for studying relationship between physio-chemical parameters.

Water containing natural population of phytoplankton was collected in high class plastic bottles from the surface by using plankton net (45 mm pore size). 125 ml of the samples were preserved with 5ml of 4% formaldehyde in the field for microscopic examination. The collections were deposited in the Environmental Biology Research Laboratory of T. M. Bhagalpur University, Bhagalpur. Camera Lucida Diagrams were made under appropriate magnification. Nygaard (1949) and Palmer (1969) indices were used to know to status of water quality. Species diversity index was calculated following Shannon-Weaver (1949) formula $H = - \Sigma$ Pi in Pi. Where, Pi = Ni/N represents the proportion of species in the community, Ni = number of individuals of a species i, N = total number of individual. Identifications of phytoplankton were made following Turner (1892), West and West (1907), Desikachary (1959), Randhawa (1959), Philipose (1967), Prescott (1969), Cramer (1984) and Sarode and Kamat (1984).

Fig. 1 Showing sampling location of River Ganga from Munger to Manihari

Results and Discussion

Seasonal variation (Pre-monsoon and Post-monsoon) in the physico-chemical complexes of different sampling stations are appended in Table 1. The fluctuations in ambient and water temperature of different stations may be due to influence of environmental temperature due to that point of time. The pH is one of the most important factors that influence the aquatic production. In the present study the pH was found to be acidic to alkaline both in pre and post monsoon. The higher alkaline state of pH might be due to enhanced chemical interaction that leads buffering and release of alkaline ions in the river water. The range of variation in turbidity values was much higher in both pre and post monsoon than the permissible limit 5 NTU prescribed by BIS (10500:2004-2005). In the pre-monsoon it ranged 5.6-17.7 NTU while in post-monsoon it ranged 12.4-29.9 NTU. In the post-monsoon shows higher turbidity values due to runoffs. It carries sands, clay, silts, organic matter, phytoplankton and other microscopic organisms. Conductivity is measure of the capability of a solution such as water in stream to pass an electric current. This is an indicator of the concentration of dissolved electrolyte ions in the water. It does not identify the specific ions in water. However, significant increases in conductivity may be an indicator that polluting discharges have entered the water. Fresh water streams ideally should have conductivity between 150 – 500 µS/cm to support diverse aquatic life (Sharon Behar, 1997). Electrical conductivity is useful to evaluate the purity of water which was ranged 271µs-395µs in pre-monsoon while in post-monsoon 222µs-383µs. TDS are composed mainly of carbonates, bicarbonates, phosphate, nitrate, calcium, magnesium, sodium, potassium and iron. In the present investigation TDS ranged in pre-monsoon was 139mg/l-201mg/l while in post-monsoon it ranged 113mg/l-195mg/l. The results indicate that in both the season at all the research stations were within the permissible limit of ISI. In the present investigation, DO was found to be in the range of 6mg/l-9.6mg/l in pre-monsoon while in post-monsoon 4.5mg/l-9.6mg/l. DO was very low (4.5mg/l) at research station-3 in post-monsoon and beyond the acceptable limit. Carbon dioxide is produced as a result of respiration of aquatic organisms. Due to respiration of organisms, carbon dioxide increases in water which subsequently changes the proportion of carbonate and bicarbonate ion (Boyd, 1981). In the present study free carbon dioxide values were observed in between 6mg/l-70mg/l in pre-monsoon while in post monsoon was 24mg/l-80mg/l. Bicarbonate alkalinity may be contamination due to leaching process through surface water during rainy season (Singh and Singh, 1999). Bicarbonate ranged was 32mg/l-40mg/l in pre-monsoon while in post-monsoon it was 26mg/l-40mg/l. Calcium and magnesium are important ions contributing towards the total hardness. Hardness has no adverse effects. Water with less than75mg/l of calcium carbonate is considered soft and above75mg/l of calcium carbonate as hard (Sawyer, 1960). According to Kannan (1991), water with hardness values more than 180mg/l is very hard. Hardness in both pre and post-monsoon was above the 75mg/l and below the 180mg/l in all sampling station. So, it falls under category of hard water. Chloride value range from 9.99mg/l-27.99mg/l. Results showed that all the sampling station samples falls within acceptable limit. Phosphorus acts as growth limiting factor and is an important nutrient for microorganisms (Odum, 1971). It is a pollution indicator, as its higher amount causes eutrophication in fresh water. The values of phosphorus ranged between 0.05 to 0.086 mg/l in both pre and post monsoon. According to Sreenivasan (1964) normal range of phosphate concentration in water is 0.1 to 0.2 mg/l. The finding result remained within the normal range during the present study. Nitrate is plant nutrient which impacts on algal population. Nitrate-nitrogen was ranged between 0.04 to 0.047 mg/l in both the season. The values were very low in all sampling station in both pre and post-monsoon. The COD ranged from 38.9mg/l-69.6mg/l in pre-monsoon while in post-monsoon 12.31mg/l - 44.8 mg/l. In pre-monsoon value of COD was higher in comparison to post-monsoon except sampling station - 1 and also it was higher than the permissible limit. The BOD ranged in pre and post-monsoon from 0.8 mg/l -7.4mg/l. In both the seasons values were low except sampling station-5 in post-monsoon.

Statistical analysis of ambient temperature showed positive correlation with water temperature while the water temperature showed the positive correlation with turbidity in pre-monsoon and in the post-monsoon positive correlated with pH and the values significant at 0.01%. pH showed positive correlation with chloride and Nitrate-nitrogen in pre-monsoon and significant at 0.01%. Conductivity showed the positive correlation with TDS and BOD in pre-monsoon but in post-monsoon positive correlation with TDS, HCO^-_3 and Cl^- and significant at 0.01%. Turbidity showed positive correlation with BOD in post-monsoon. TDS showed positive correlation with BOD in pre-monsoon but in post-monsoon showed positive correlation with HCO^-_3 and Cl^- and significant at 0.01%. Cl^- showed positive correlation with NO_3-N in pre-monsoon and significant 0.01%.

Altogether 57 genera and158 species of phytoplankton have been identified in pre and post-monsoon at all eight sampling station. They belong to Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae. There distribution has been given in Table-2. The Bacillariophyceae forms outnumbered than the other groups and covered 20 genera and 69 species of the total number of the species. Chlorophyceae were next to Bacillariophyceae encompassing 22 genera and 58 species. Cyanophyceae population followed the Chlorophyceae and these were represented by 13 genera and 28 species. The Euglenophyceae were represented by 2 genera and 3 species. Based on the percent composition, the phytoplankton belonging to Bacillariophyceae (49.15% and 64.7%) were dominant followed by Chlorophyceae (38.98% and 26.47%), Cyanophyceae (11.86% and 8.82%) at first sampling station in pre and post- monsoon respectively. At sampling station second Bacillariophyceae (51.42% and 53.12%) were dominant followed by Chlorophyceae (28.57% and 40.62%), Cyanophyceae (20% and 6.25%) whereas, at sampling station third Bacillariophyceae (57.69% and 53.57%) were abundant followed by Chlorophyceae (30.76% and 25%), Cyanophyceae (11.53% and 21.42%). At station fourth, phytoplankton belonging to Bacillariophyceae (48.43% and 58.18%) were dominant followed by Chlorophyceae (34.37% and 21.81%), Cyanophyceae (17.18% and 18.18%) and Euglenophyceae (1.81% only in post-monsoon). At sampling station fifth Bacillariophyceae (40.22% and 34.48%), Chlorophyceae (35.63% and 47.12%), Cyanophyceae (21.83% and 17.24%) and Euglenophyceae (2.29% and 1.14%) in pre and post-monsoon respectively but in pre- monsoon Bacillariophyceae were dominant while in post-monsoon Chlorophyceae. At sampling station sixth Bacillariophyceae (48.57% and 48.48%) were dominant followed by Chlorophyceae (45.71% and 45.45%) and Cyanophyceae (5.71% and 6.06%) whereas, at sampling station seventh Bacillariophyceae (48.48% and 41.66%), Chlorophyceae (42.42% and 50%), Cyanophyceae (9.09% and 4.16%) and Euglenophyceae (4.16% only in post- monsoon) were found. In sampling station seventh Bacillariophyceae was dominant in pre monsoon but in post-monsoon Chlorophyceae was dominant. At sampling station eight Bacillariophyceae (40% and 58.33%) were dominant followed by Chlorophyceae (33.33% and 25%) and Cyanophyceae (16.66% and 16.66%). Over all the sampling station Bacillariophyceae were dominant followed by Chlorophyceae and Cyanophyceae in pre-monsoon except at sampling station fifth and seventh where Chlorophyceae was dominant in post-monsoon. The phytoplankton count registered higher value in pre-monsoon. It is reported that excessive growth of certain algal genera like *Scenedesmus*, *Anabaena*, *Oscillatoria* and *Melosira* indicate nutrient enrichment of aquatic bodies (Kumar, 1990; Zargar and Ghosh, 2006). A number of workers have reported many algal species as indicators of water quality (Nandan and Aher, 2005; Zargar and Ghosh, 2006; Kumar and Choudhary, 2010). *Scenedesmus quadricauda, Scenedesmus obliquas, Scenedesmus dimorphus, Chlorella vulgaris, Pediastrum duplex, Actinastrum hantzschii, Coelastrum microporum, Synedra ulna, Synedra acus, Melosira granulata, Nitzschia acicularis, Cyclotella meneghiniana* and *Oscillatoria princeps* have been found in this stretch of the river Ganga and these are the most pollution tolerant species of algae (Palmer, 1969). According to pollution index of algal genera (Palmer, 1969), the index value was 32 indicating of organic pollution. Nygaard (1949) proposed indices to evaluate the organic pollution of water body on the basis of algal groups. These indices showed the values of chlorophycean and cyanophycean were eutrophic nature of water body while the euglenophycean and diatoms showed oligotrophic nature of water body. In this stretch of river is subjected to acute pollution due to addition of industrial effluents, fertilizers from agricultural lands, domestic sewage of municipal area and other sources. Progressive enrichment of water with nutrients leads to mass production of algae. The pre and post-monsoon variation of species diversity index is given in Table 3. The index is based on the principle that clean water, the species diversity is high while, in polluted water species diversity becomes low. The Shannon-Weaver diversity index proposed as diversity index greater than (>4) is clean water, between 3- 4 is mildly polluted water; between2-3 is moderately polluted water and less than 2(<2) is heavily polluted water. The index computed in the present investigation showed that phytoplankton species diversity ranged from 0.117-1.675 in the sampling station first (in post-monsoon), second, third, sixth, seventh and eighth in both pre and post- monsoon indicating heavily polluted because it falls under index less than 2(<2). Its range in sampling station first (pre-monsoon), fourth and fifth (both pre and post- monsoon) are 4.013-8.631 representing clean water. The present investigation clearly reveals that in respect of pollution, phytoplankton were more tolerant to pollution. The attempt emphasizes the need of using phytoplankton as effective and suitable technique of bio monitoring for assessment of river water quality.

Table 1: Physico-chemical characteristics of water of river Ganga from Munger to Manihari (Bihar), in Pre-monsoon and Post- monsoon, 2014

SS	GPS position	Seasons	A T (˚C)	W T (˚C)	Turbidity (NTU)	Conductivity (µs)	TDS	pH	DO	FCO_2	HCO_3^-	TH	Cl^-	$PO_4 – P$	$NO_3 – N$	COD	BOD
1	*N 25°23.019’ E 86°27.562’*	Pre- mons.	33	25.8	8.7	349	178	7.9	9.6	48	33	140	23.97	0.067	0.041	45.2	0.8
		Post-mons.	21	24.1	19.2	294	149	8.8	9.6	32	36	126	13.99	0.05	0.041	12.31	0.8
2	*N 25°19.813’ E 86°34.881’*	Pre-mons.	31.8	25.3	8.2	320	163	7.6	8.3	64	44	160	15.98	0.057	0.042	38.9	1.3
		Post-mons.	25	24	12.4	383	195	8.6	4.5	80	40	170	19.99	0.056	0.040	20.39	0.8
3	*N 25°15.285’ E 86°44.353’*	Pre-mons.	23.5	24.6	8.1	350	178	7.9	8.4	70	36	144	22.97	0.065	0.042	54.7	2.8
		Post-mons.	15	17	25.5	363	169	6.9	8.8	48	40	110	15.99	0.062	0.044	32.8	0.4
4	*N 25°16.189’ E 87°01.942’*	Pre-mons.	28	24.3	5.6	365	186	8.2	9	44.8	36	146	25.97	0.064	0.044	63.2	1.8
		Post-mons.	21	18.8	29.9	329	167	7.2	6	46	38	136	15.99	0.080	0.043	39.6	2
5	*N 25°15.900’ E 87°13.528’*	Pre-mons.	27	24.1	7.3	395	201	8.1	6	50	40	142	27.99	0.084	0.044	69.6	1.6
		Post-mons.	13.4	17.7	23.9	346	173	7.4	9	45	38	170	17.99	0.072	0.043	44.8	7.4
6	*N 25°24.995’ E 87°15.187’*	Pre-mons.	32	25.2	8.5	289	147	8.2	8.4	6	40	140	27.99	0.077	0.047	44.8	1.3
		Post-mons.	14	17	21.99	364	187	6.4	9	24	36	162	11.99	0.075	0.046	42	2.8
7	*N 25°27.726’ E 87°23.617’*	Pre-mons.	31.3	24.9	17.7	271	139	7.5	6	34	32	126	16.98	0.076	0.042	50.7	2
		Post-mons.	29.5	24.3	17.7	222	113	8.6	9.6	38	26	120	9.99	0.086	0.040	26.31	0.8
8	*N 25°20.673’ E 87°36.990’*	Pre-mons.	32.2	24.9	6.7	324	165	7.6	7.6	18	32	128	20.97	0.054	0.043	48	1.7
		Post-mons.	14.2	17.3	29.32	269	137	7.8	9.6	28	30	150	11.99	0.069	0.045	28.9	2.8

* Except p^H, all other variables expressed in ppm or mg/l or otherwise mentioned. TDS= Total Dissolve Solid, DO= Dissolved Oxygen, FCO_2 = Free-carbon dioxide, CO_3^{--} = Carbonate alkalinity, HCO_3^- = Bicarbonate alkalinity, TH = Total Hardness, Cl^- = Chloride, PO_4–P = Phosphate – phosphorus, NO_3-N = Nitrate – nitrogen, COD= Chemical oxygen Demand, BOD=Biological Oxygen Demand, AT. = Ambient Temperature, WT. = Water Temperature, Abs. = Absent. SS- 1= Kastharni Ghat Munger, SS-2 = Confluence Burhi Gandak, Munger, SS-3= LCT Ghat Sultanganj, Bhagalpur, SS-4= Bridge Ghat Bhagalpur, SS-5=LCT Ghat Kahalgaon, Bhagalpur, SS- 6= Confluence Ganga+Kosi Kursela, Katihar, SS- 7= UchlaGhat Karahagola, Katihar, SS- 8= Manihari Singhal Tola Ghat, Katihar, Pree-mons. =Pree-monsoon, Post-mons. =Post-monsoon, SS= Sampling Station

Table 2: Occurrence of different classes of phytoplankton in Ganga River from Munger to Manihari in Pre-monsoon and Post- monsoon, 2014

Sampling station (SS)	SS - 1		SS - 2		SS - 3		SS - 4		SS - 5		SS - 6		SS - 7		SS - 8	
Seasons / **Phytoplankton**	Pre-mon	Post - mon	Pre-mon	Post-mon	Pre-mon	Post-mon	Pre-mon	Post - mon	Pre-mon	Post - mon	Pre-mon	Post - mon	Pre-mon	Post - mon	Pre-mon	Post - mon
Chlorophyceae																
Pediastrum simplex Meyen	-	-	+	+	-	-	+	-	-	+	-	-	+	-	+	+
Pediastrum duplex Meyen	-	+	-	+	-	-	+	-	-	+	+	-	-	+	-	-
Pediastrum biradiatum Meyen	-	-	-	-	-	-	-	-	+	-	+	+	-	+	-	-
Pediastrum tetras (Ehr.) Ralfs	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Pediastrum ovatum (Ehr.) A. Braun	+	+	-	-	+	-	+	+	-	-	-	+	-	-	-	-
Spirogyra parvula (Trans.) Czurda	+	-	-	-	+	-	-	-	-	+	+	-	-	-	-	-

Spirogyra daedalea Lagerheim	+	-	-	+	+	-	-	-	-	+	+	+	-	-	-	-
Spirogyra decimina (Mull.) Kutz.	+	+	-	+	-	-	+	+	-	+	+	+	-	+	-	-
Spirogyra hassallii (Jenn.) Petit.	+	+	-	-	+	-	+	+	-	-	+	+	+	-	+	-
Spirogyra hyaline Cl.	+	-	+	-	-	+	-	+	+	+	-	+	-	+	-	-
Spirogyra rhizoids Randhawa	+	-	-	+	-	-	-	-	+	+	+	+	-	+	-	+
Spirogyra orientalis W.& G.S. West	+	-	-	-	-	-	+	-	+	+	-	+	+	-	-	-
Chlorella vulgaris Beijerinck	-	-	-	+	-	-	+	+	+	-	-	+	+	+	-	+
Coelastrum microporum Naegeli	-	-	-	-	+	-	+	-	-	+	+	-	+	+	-	-
Scenedesmus *obliquus* (Turpin) Kuetz.	-	+	-	-	-	-	+	-	+	+	-	-	+	-	-	-
Scenedesmus protuberans Fritsch et Rich	+	-	-	-	-	+	-	-	-	+	-	-	+	-	-	-
Scenedesmus dimorphus (Turpin) Kuetz.	+	-	-	-	-	+	+	-	+	+	+	-	+	-	-	-
Scenedesmus alternans (Reinsch) Hansgirg	-	-	-	-	-	-	+	-	+	+	+	-	-	-	-	-
Scenedesmus quadricauda (Turpin) Brebisson	+	-	-	-	-	-	+	-	-	+	+	-	-	+	-	-
Scenedesmus platydiscus (G.M. Smith) Chodat	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-
Scenedesmus longus Meyen	+	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-
Scenedesmus bijugatus (Turpin) Kuetz.	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-
Scenedesmus tropicus Crow	+	-	-	-	-	-	-	-	+	-		-	-	-	-	-
Scenedesmus australis Playfair	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-
Scenedesmus arcuatus Lemmermann	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-
Scenedesmus bernardii G.M. Smith	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-
Scenedesmus parvus (G.M. Smith) Comb.Nov.	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-
Ankistrodesmus convolutes Corda	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Actinastrum hantzschii Lagerheim	+	-	+	-	+	-	-	+	-	-	+	+	+	-	-	-
Hydrodictyon reticulatum (Linn.) Lagerheim	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-
Selenastrum gracile Reinsch	-	-	-	-	-	-	-	-	-	+	-	-	+	+	-	-
Oocystis macrospora (Turner) Brunnthaler	+	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-
Oocystis elliptica W.West	-	-	-	-	+	-	-	-	+	-	+	-	-	-	-	-
Oocystis lacustris Chodat	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Staurastrum longibrachiatum (Borge) Gutw.	-	-	-	+	-	-	-	-	+	+	-	-	+	-	-	-
Staurastrum wittrockii Turner	-	+	-	-	-	-	+		+	-	-	-	-	-	+	-
Arthrodesmus curvatus Turner	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Characium acuminatum A.Braun ex Kuetz.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Cladophora kuetzingianum Grun.	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Cladophora holsatica Kuetz.	-	-	+	+	-	+	-	-	-	+	-	-	-	-	-	-
Hyalotheca dissiliens (J.E. Smith) Breb.	+	-	-	-	-	+	-	-	+	+	-	-	-	+	-	-
Hyalotheca indica Turner	-	-	+	-	-	-	+	-	+	+	-	-	-	-	-	-
Hyalotheca mucosa (Dillw.) Ehr.	-	-	-	+	-	-	+	+	+	-	-	-	-	-	-	-
Desmidium baileyi (Ralfs) Nordst.	+	-	-	-	-	-	+	-	+	+	-	+	+	+	+	-
Oedogonium varians Wittrock and Lundell	-	-	-	-	-	-	+	-	+	+	-	-	-	-	+	-
Volvox aureus Ehr.	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Micractinium pusillum Fres.	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Cosmarium galeritum Nordst.	+	-	-	+	-	-	+		-	+	-	-	-	-	-	-
Cosmarium ctenoideum Turner	+	+	-	-	-	-	-	+	+	+	-	-	-	-	-	-
Cosmarium sub-circulare Turner	-	+	-	-	+	+	-	+	+	+	-	-	-	-	-	-

Cosmarium contractum Kirchn.	-	-	+	-	-	-	+	-	+	-	-	-	-	-	-	-
Cosmarium microsphinetum Nordst.	-	-	+	-	-	+	-	-	-	+	-	-	-	-	-	-
Cosmarium pseudocornatum Turner	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Cosmarium rectosporum Turner	+	-	-	-	-	-	-	-	-	+	-	-	-		-	-
Euastrum inermius Nordst.	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Closterium parvulum Nageli	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Closterium ehrenbergii Menegh	-	-	-	+	-	-	+	+	+	+	-	+	-	-	-	-
Closterium incurvum Breb.	-	-	+	-	-	-	-	-	+	-	+	-	-	-	-	-
Bacillariophyceae																
Synedra ulna (Nitz.) Ehr.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Synedra acus Kuetz.	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-
*Melosira granulata (*Ehr.) Ralfs	+	+	+	+	+	+	+	+	-	+	+	+	+	-	+	-
Melosira islandica O. Muell.	+	-	+	-	-		+	+	+	+	+	-	+	-	+	-
Melosira islandica O. Muell. v. *helvetica* O. Muell.	+	+	-	-	-	+	+	-	+	-	-	+	+	-	+	-
Melosira juergensii Agardh	-	+	-	-	+	+	+	-	+	+	-	+	-	-	+	-
Nitzschia vasnii Gandhi	-	+	-	-	-	+	-	-	-	+	-	-	+	-	-	-
Nitzschia maharashtrensis Turner	-	-	+	-	-	-	+	-	+	-	-	+	+	-	-	-
Nitzschia calida Grun.	-	-	-	-	-	-	+	-	+	-	+	-	+	+	-	-
Nitzschia clausii Hantzsch	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Nitzschia acicularis W. Smith	+	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-
Nitzschia intermedia Hantzsch	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
Nitzschia dentriculata Grun.	-	+	-	+	-	-	-	+	-	+	+	-	-	-	-	-
Nitzschia lorenziana Grun.	-	+	+	-	-	-	+	-	-	+	-	-	-	-	-	-
Nitzschia frustulum (Kuetz.) Grun.	-	-	-	-	+	-	-	-	-	+	-	-	-	+	-	-
Navicula dicephala (Ehr.)W. Smith	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-
Navicula confervacea Kuetz.	-	-	-	-	-	-	+	+	-	-	-	-	+	-	-	+
Navicula similis Krasske	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Navicula halophila (Grun.) Cl.	+	-	-	+	-	-	-	-	+	+	-	-	-	-	-	-
Navicula radiosa Kuetz.	+	-	-	+	+	-	+	+	+	+	-	+	-	-	-	-
Navicula disjuncta Hustedt	+	-	-	-	-	+	+	+	+	+	-	+	-	-	-	+
Navicula viridula Kuetz.	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Navicula bacillum Ehr.	-	+	+	-	-	-	-	-	+	-	-	-	+	-	-	-
Navicula hustedtii Krasske	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Navicula iniqua Krasske	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-
Navicula rostellata Kuetz.	-	+	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Cymbella affinis Kuetz.	+	-	+	-	-	-	+	+	-	+	-	-	-	+	-	-
Cymbella tumidula Grun.	+	-	+	+	-	-	+	-	+	-	-	-	-	-	-	-
Cymbella tumida (Breb.) V.H.	+	+	-	+	-	-	+	+	-	-	+	-	-	+	-	-
Cymbella powaiana Gandhi	-	+	-	+	-	-	-	+	-	-	-	-	+	+	-	-
Cymbella gracilis (Rabh.) Cl.	+	+	-	-	+	-	-	+	+	+	+	+	+	-	-	-
Cymbella bengalensis Grun.	+	-	-	-	-	+	-	-	+	+	+	-	-	-	-	-
Cymbella cymbiformis (Ag.) Kuetz.	+	+	-	+	+	+	+	+	+	-	+	-	-	+	-	+
Fragillaria brevistriata Grun.	+	-	-	-	-	-	+	-	-	+	+	-	-	-	-	-
Fragillaria rumpens (Kuetz.) Carl.	-	+	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Fragillaria construens (Ehr.) Grun.	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	+

Pinnularia virids (Nitz.) Ehr.	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-	-
Pinnularia borealis Ehr.	+	-	-	-	+	-	-	+	+	-	-	-	+	-	-	-
Pinnularia brevicostata Cl. v. *indica* Gandhi	+	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
Pinnularia aestuarii Cl.v.*interrupta* (Hust.) A.Cl.	-	-	-	+	-	-	+	-	-	+	-	-	-	-	-	-
Pinnularia divergens W. Smith	-	-	-	-	-	+	-	+	-	+	-	-	-	-	-	-
Pinnularia gibba Ehr.	-	+	-	+	-	+	-	-	+	-	+	-	-		-	-
Pinnularia stomatophoroides Mayer v. ornata A.Cl.	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Gomphonema subapicatum Fritch et Rich	+	-	-	-	+	+	-	+	+	+	-	-	-	-	-	-
Gomphonema constrictum Ehr.	+	+	-	+	+	-	+	-	+	+	-	-	-	+	-	-
Gomphonema moniliformae Gandhi	+	-	-	+	-	-	+	+	-	-	+	-	-	-	-	-
Gomphonema lingulatum Hustedt	-	-	+	-	-	-	-	-	+	+	+	-	-	-	-	-
Gomphonema lanceolatum Ehr.	-	+	-	-	+	-	-	-	+	-	-	+	-	-	-	-
Gomphonema gracile Ehr.	+	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-
Gyrosigma attenuatum (Kuetz.) Rabh.	+	-	-	-	-	-	-	+		+	-	-	-		-	-
Gyrosigma acuminatum (Kuetz.) Rabh.	-	+	+	-	-	+	+	+	-	-	+	-	-	-	-	-
Gyrosigma scalproides (Rabh.) Cl.	+	-	+	-	-	+	-	-	+	-	-	+	-	+	-	+
Surirella icro Kuetz.	-	-	+	-	-	+	-	+	-	+	-	-	-	-	-	-
Surirella robusta Ehr.	-	-	-	+	-	-	-	+	+	-	-	-	+	-	-	-
Surirella tenera Greg.	-	+	+	-	-	-	-	-	+	-	-	-	-	-	-	+
Surirella capronioides Gandhi	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Mastogloia smithi Thwaites	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-
Stauroneis anceps Ehr.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Cymatopleura solea (Breb.) W. Smith	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-
Achnanthes gibberula Grun.	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Neidium dubium (Ehr.) Cl.	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-	-
Cyclotella meneghiniana Kuetz.	+	-	-	+	+	-	+	-	-	-	+	-	-	-	-	-
Cyclotella glomerata Bachman	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Anomoeoneis brachysira (Breb.) Grun. v.*thermaiis* A.Cl.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Amphora ovalis (Kuetz.) v. affinis Kuetz.	+	-	-	-	-	-	+	-	+	-	-	+	-	-	-	+
Amphora normanii Rabh.	-	-	-	-	-	+	-	+	-	-	+	-	-	-	-	-
Eunotia monodon Ehr.	-	+	-	-	+	-	+	-	+	-	-	-	-	-	-	-
Eunotia laurians (Ehr.) Grun.	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-
Pleurosigma angulatum (Quekett) W. Smith	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Cyanophyceae																
Anabaena spiroides Klebahn	+	-	-	-	-	-	+	+	-	-	+	-	-	+	-	-
Anabaena anomala Fritsch	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Aphanocapsa grevillei (Hass.) Rabenh.	+	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-
Aphanocapsa biformis A.Br.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
Aphanocapsa elachista v. *conferta* W. et G. S. West	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Aphanocapsa littoralis Hansgirg	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Aphanothece microscopica Nag.	-	-	+	-	-	-	+	+	-	-	-	-	+	-	-	-
Aphanothece nidulans Richter, P.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Aphanothece naegelii Wartm.	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-

Microcystis floa-aquae (Wittr.) Kirchner	+	+	+	+	-	+	+	+	+	-	-	-	+	-	-	-
Microcystis viridis (A.Br.) Lemm.	-	+	-	-	-	+	-	+	-	+	-	-	-	-	-	-
Microcystis robusta (Clark) Nygaard	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	+
Merismopedia tenuissima Lemm.	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-
Merismopedia elegans A.Br.	-	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-
Oscillatoria princeps Vaucher ex Gomort	+	-	+	+	+	+	-	-	+	+	+	-	+	-	+	+
Oscillatoria subbervis Schmidle	-	-	-	-	-	+	+	-	+	-	-	-	-	-	-	-
Oscillatoria curviceps Ag. Ex Gomont	-	+	-	-	-	-	+	+	+	+	-	+	-	-	-	-
Lyngbya spirulinoides Gomont	+	-	+	-	-	+	+	+	+	-	-	-	-	-	-	-
Lyngbya contorta Lemmn.	-	-	+	-	+	-	-	-	-	+	-	-	-	-	-	-
Arthrospira platensis (Nordst.) Gomont	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Spirulina gigantean Schmidle	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-
Spirulina meneghiniana Zanard	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Gloeocapsa punctata Nag.	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Chroococcus minor (Kuetz.) Nag.	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Nostoc ellipsosporum (Desm.) Rabenh.	+	-	+	-	-	-	-	-	+	-	-	-	-	-	+	-
Nostoc calcicola Breb.ex Born.	-	-	-	-	-	-	+	-	-	+	-	+	-	-	-	-
Nostoc carneum Ag.ex Born. et Flah.	-	-	-	-	+	-	-	+	-	+	-	-	-	-	-	-
Phormidium fragile (Meneghini) Gomont	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Euglenophyceae																-
Euglena proxima Dangeard	-		-	-	-	-	-	-	+	-	-	-	-	+	-	-
Euglena acus Hueb.	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Phacus orbicularis Hueb.	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-

Table 3: Species diversity index (Shannon and Weaver, 1949) in different sampling station of River Ganga, 2014

Seasons	SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	SS-7	SS-8
Pre-monsoon	5.12	1.675	1.293	5.678	7.902	1.675	1.201	0.117
Post-monsoon	1.577	1.022	1.675	4.013	8.631	1.111	1.022	0.195

Index: > 4 clean water, 3–4 = mildly polluted water, 2–3 = moderately polluted water, < 2 = heavily polluted water

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